Charged Kaons at the Main-Injector

Peter S. Cooper   Fermilab   February 15, 2003

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QUESTION - What does it take to falsify The Standard Model hypothesis that to only source of CP violation is the phase of V_{td}?

I. Three is the minimum number of measurements to be made. (Two parameters to be determined + at least 1 test.)
II. Your experiments shall be done properly and work!
III. Your experimental errors must be well and truly estimated.
IV. Your theoretical assumptions and error estimates shall be without sin - or the appearance of sin.

This talk is available at: http://www.fnal.gov/projects/ckm/CKM-HEP_Facilities.pdf

What measurements might satisfy these requirements? (Bob Cahn's summary in my words)

$\sin(2\beta)$ in $B_d^0 \rightarrow \psi K_s^0$, $B_d^0 \rightarrow \phi K_s^0$

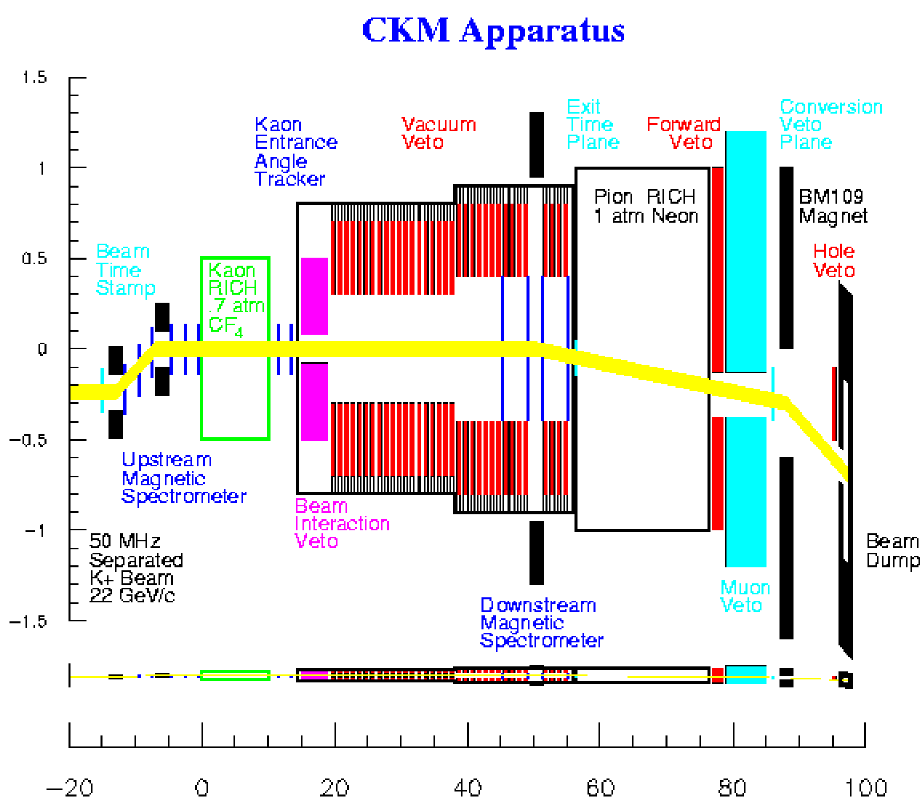
$K^0 \rightarrow \pi^0 \nu \bar{\nu}$, $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

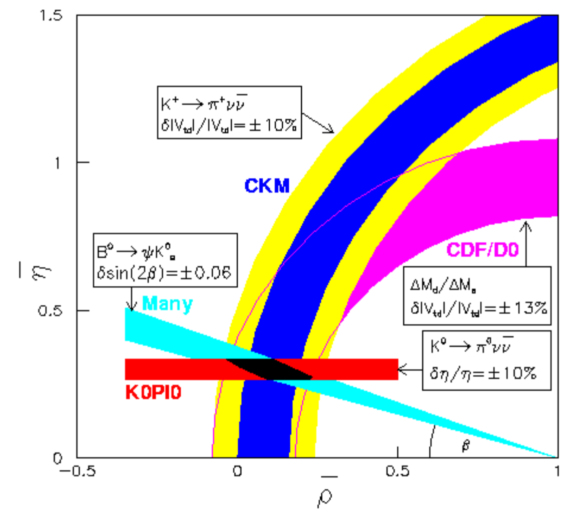
$\Delta m_d / \Delta m_s$ in B_d^0 and B_s^0 Decays (?)

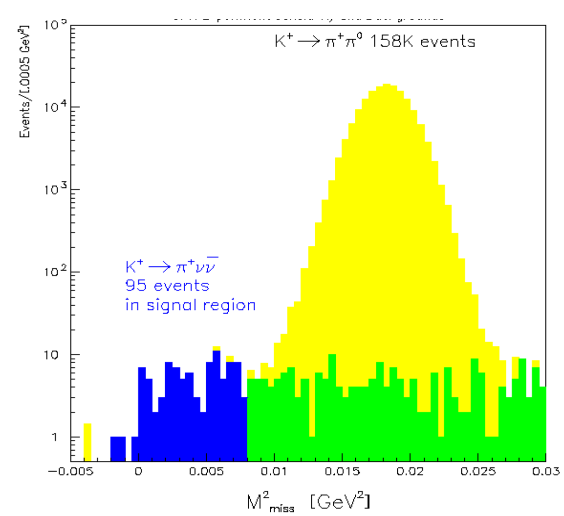
Others are either experimentally inaccessible, polluted with backgrounds and/or rely on theoretical calculations (eg: lattice) which aren't robust enough to support the conclusion that the Standard Model is wrong. These measurements can confirm the SM and improve the measurements of [ρ,η]. If $\alpha+\beta+\gamma < 180^0$ no one will believe that the Lattice is right and the SM wrong - even if this is true!

CKM Measuring $|V_{td}|$ with $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- Decay in flight in a separated K^+ beam at 22 Gev/c.
- Redundant high rate detectors and veto systems.







Q1 What kind of physics at the LHC energy scale is the CKM measurement of $|V_{td}|$ sensitive to?

D'Ambrosio & Isidori , Phys.Lett.B530:108(2002)

$K^+ \to \pi^+\nu\nu$: A rising star on the stage of flavor physics

- Generic SUSY enhances $\pi\nu\nu$ rates
- MSSM & MFV do not affect $\pi\nu\nu$ rates => Non SM rate can't be from MSSM or MFV
- $\pi^+\nu\nu$ rate >1.32x10^{-10} => New physics.
- Flavor blind new physics can cancel in $\Delta m_d / \Delta m_s$, not so in $\pi\nu\nu$ rates.
- SUSY structure to $B \to \pi\, l^+ l^-$ parallel to $K \to \pi\nu\nu$.

Also See:

Yosef Nir, **CP Violation: The CKM Matrix and New Physics**, hep-ph/0208080,
Gino Isidori, **Kaon Physics and the flavor problem**, hep-ph/0301159
CKM Proposal - Chap 2 Sec 3 (Summary table on next slide)
(http://www.fnal.gov/projects/ckm/documentation/public/proposal/proposal.html)

From:

CKM Proposal

Chapter 2

Section 3

	$BR(K^+ \to \pi^+ \nu\bar\nu)$	$BR(K_L^0 \to \pi^0 \nu\bar\nu)$	$BR(K_L^0 \to \pi^0 e^+ e^-)_{CP-dir}$	Note
Standard Model prediction	$(7.7 \pm 2.1) \cdot 10^{-11}$	$(2.3 \pm 0.7) \cdot 10^{-11}$	$(3.6 \pm 1.1) \cdot 10^{-12}$	
Experimental data	$(15^{+34}_{-12}) \cdot 10^{-11}$ [6]	$< 5.9 \cdot 10^{-7}$ [59] (90% C.L.)	$< 5.1 \cdot 10^{-10}$ [60] (90% C.L.)	From isospin symmetry there is a model independent limit: $BR(K_L^0 \to \pi^0 \nu\bar\nu) < 4.4 BR(K^+ \to \pi^+ \nu\bar\nu) \leq 2.9 \cdot 10^{-9}$ (90% C.L.) [34]

Models with new physics	$R_{(1)} = \mathrm{BR}(\pi^+ \nu\bar\nu) / \mathrm{BR}(\pi^+ \nu\bar\nu)_{SM}$	$R_{(2)} = \mathrm{BR}(\pi^0 \nu\bar\nu) / \mathrm{BR}(\pi^0 \nu\bar\nu)_{SM}$	$R_{(3)} = \mathrm{BR}(\pi^0 e^+ e^-)_{CP-dir} / \mathrm{BR}(\pi^0 e^+ e^-)_{CP-dir SM}$	
Super symmetry models with general flavor and CP violation and with modification of $Zd\bar s$ structure [47, 48, 50]	< 4	$< 14 - 18$	$< 22 - 29$	The most probable limitations are: $R_{(1)} < 2.2$ $R_{(2)} < 4.3$ $R_{(3)} < 10$
[46] (with some additional mechanisms)	≤ 3 ($\leq 6,5$)	≤ 8 (< 45)	≤ 7 (< 45)	Values of $R_{(3)} \gtrsim 10$ can be due to influence of chromomagnetic operators. Very large values of $R_{(1)}, R_{(2)}$ and $R_{(3)}$ as a rule have been obtained without taking into account all experimental limitations ([45]), or by fine tuning of some model parameters and are not very probable.
[45]	< 12	< 130	≤ 120	

Table 3: Branching ratios $BR(\pi^+ \nu\bar\nu)$, $BR(\pi^0 \nu\bar\nu)$ and $BR(\pi^0 e^+ e^-)_{CP-dir}$ for various new physics scenarios.

	$R_{(1)}$	$R_{(2)}$	$R_{(3)}$	
Minimal SUSY with Minimal Flavor Violation (MFV). No new mechanisms of CP violation [49, 50]	$0.65 - 1.03$	$0.41 - 1.03$	$0.48 - 1.1$	The decay probabilities are modified due to the supersymmetry corrections in the loop diagrams. In this model the decay probabilities as a rule are reduced in comparison with SM predictions.
SUSY with real CKM matrix and new mechanisms of CP violation (sd transition with gluino exchange) [53].	$0.2 - 2$	$\ll 1$		$R_{(2)}$ is very small since the CKM phase is $\simeq 0$ and the gluino exchange mechanism makes very small contributions to $K_L^0 \to \pi^0 \nu\bar\nu$.
Model with 4 fundamental generations of quarks and leptons [44]	$0.9 - 6$	$0.2 - 36$		Instead of a unitary triangle, there is instead a unitary quadrangle
Technicolor [54]	$< 1 - 10$	$< 1 - 10$		$K^+ \to \pi^+ \nu\bar\nu$ data can be used to obtain the limits for the parameters of technicolor models.
Model with lepton flavor violation for the decay $K_L^0 \to \pi^0 \nu_i \bar\nu_j$ [34]		CP conserving process can be dominant for this decay		For SM CP conserving decay $K_L^0 \to \pi^0 \nu\bar\nu$ is very small ($\sim 10^{-4}$) [52].
L-R model with W_L and W_R and X_L and X_R amplitudes. In this model there is an additional scalar interaction which gives a CP conserving input to $K \to \pi\nu\bar\nu$ [55]	1	1.3		In this model the scalar operator gives additional CP conserving input even to $K_L^0 \to \pi^0 \nu\bar\nu$ (in distinction from V-A interaction of SM). Additional interaction modifies the soft part of π^0 momentum spectrum in $K_L^0 \to \pi^0 \nu\bar\nu$ and increases $R_{(2)}$ by $\sim 30\%$.
Anomalous interactions in the triple boson WWZ vertex [56]	$0.1 - 2.8$			It was shown that if the anomalous coupling constant of WWZ interaction Δg_1^z vary from -0.2 to +0.2, the ratio $R_{(1)}$ can vary from 0.1 up to 2.8. This ratio is not sensitive to Δg_5^z.
Several variants of MSSM, two doublet Higgs models, several other theories [19, 42, 43, 57, 58]	1	1		If the quark mixing and CP violation is governed by the properties of CKM matrix (in the same way as in the SM) the branching ratios of $K \to \pi\nu\bar\nu$ decays would be the same as in the SM.

Table 3: (continuation)

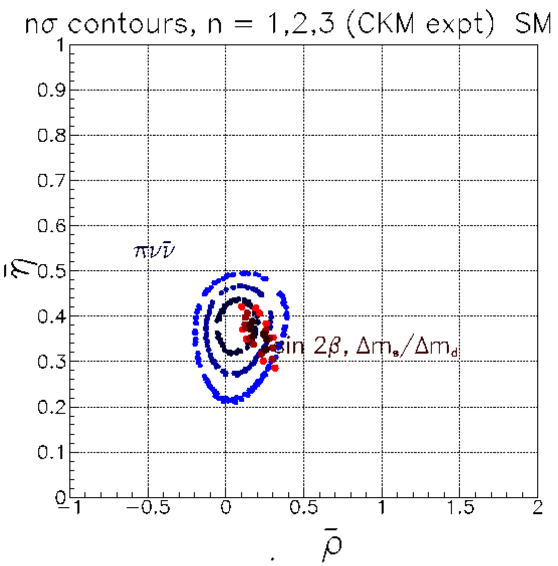
Q2 What is the impact on the determination of the unitarity triangle, given other measurements, present and expected, on CP violation and weak mixing and decays?

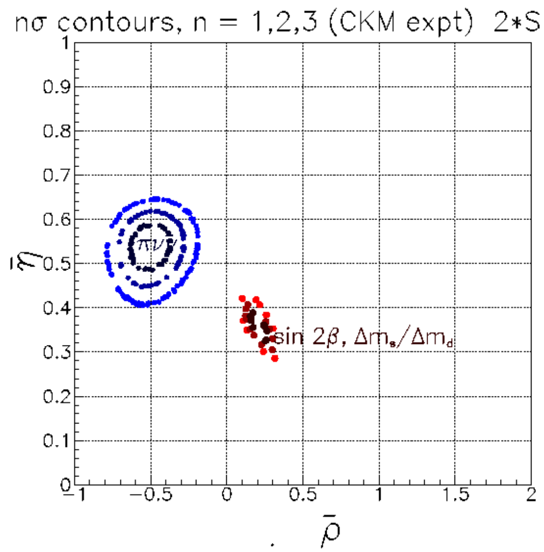
Restricting ourselves to theoretically and experimentally robust measurements CKM Fitter assuming (Dave Jaffe - BNL):

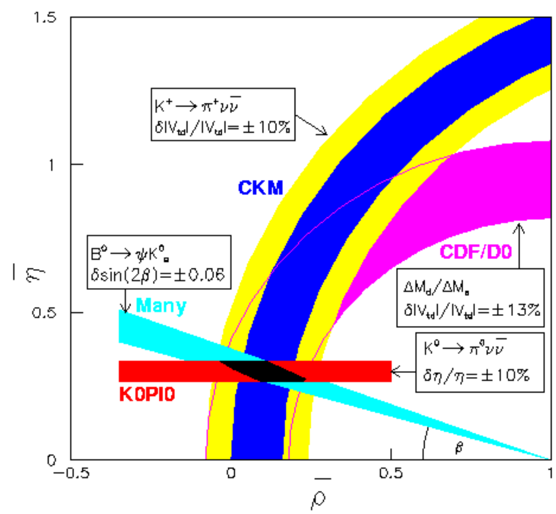
$$\sin 2\beta = 0.75 \pm 0.02$$

$$\Delta m_s / \Delta m_d = 17 \pm 1.7\ \mathrm{ps}^{-1}$$

$\Gamma(\pi\nu\nu)$ = sm	$\Gamma(\pi\nu\nu)$ = 2xsm	expected sensitivities







Q3 How optimistic on the performance of the detector and beam components is one being in order to get 100 events, the level of background quoted and a 10% measurement of $|V_{td}|$.

- CKM is designed using only demonstrated technologies – NO R&D!
  Serious technical review has validated the experiment
  All systems are prototyped and checked with test beam
  Background rejection is conservatively estimated
  BNL E787 result demonstrates no uncontrolled physics backgrounds

- We require $5\text{x}10^{12}$ Main injector protons/spill (15% of MI capability)
  Detectors are required to handle twice the design flux

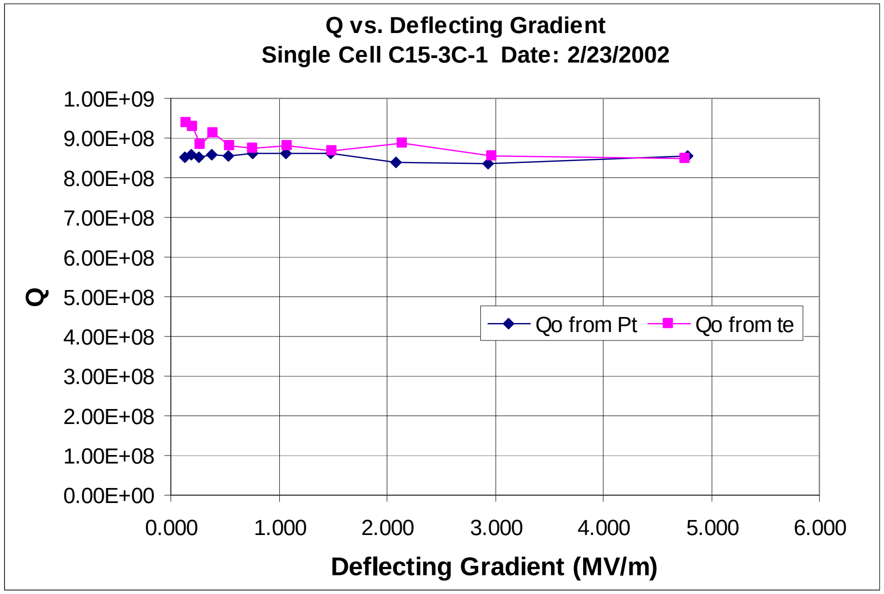
- 10% measurement of $|V_{td}|$ is 6% from statistics and 8% from charm mass uncertainty. Twice the background or ½ the signal 10% => 12%

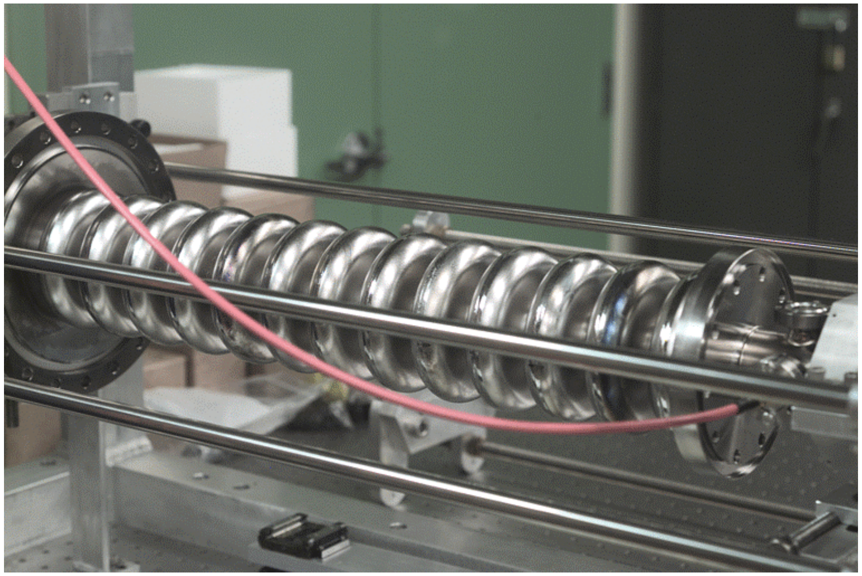
- "*Paranoid from the outset*"

C1 Technical Concern from Approval review: Separated BEAM SCRF status

•Require 5 MeV/m deflecting gradient
Have achieve this in prototype 1 and 3 cell cavities

•Design requires 12 Structures of 13-cell cavities
1st prototype built and tested – tuning can be fun. (OK now)





C2 Technical Concern from Approval review: Strawtubes operating in vacuum is a potential *showstopper*

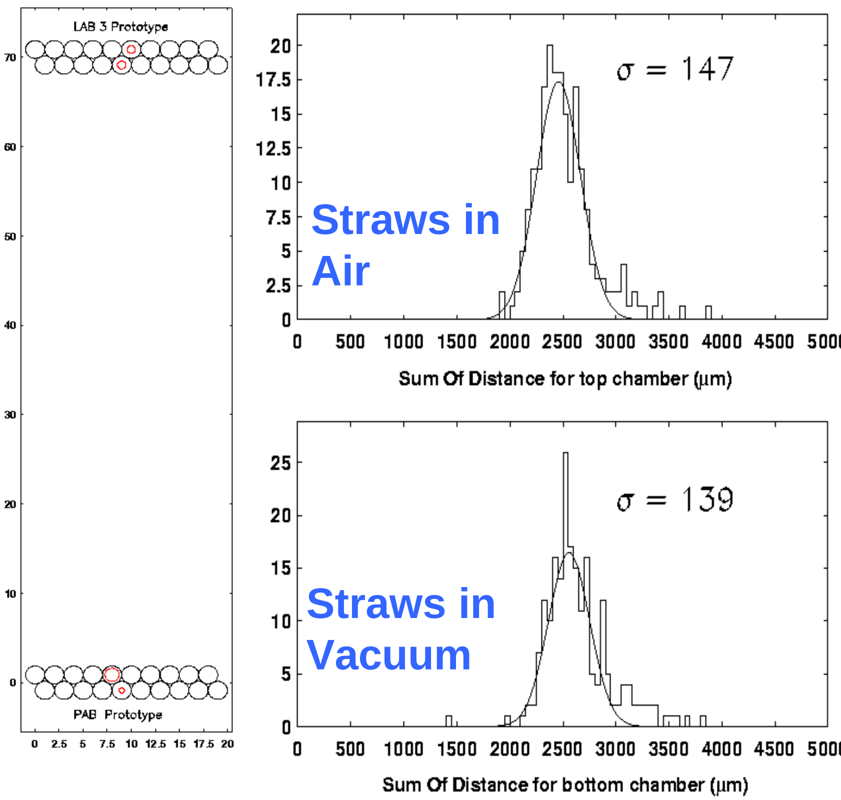
Prototype built after BNL871 design

- All chamber specs achieved
- 100 μm resolution, 98% efficiency

Tested in vacuum with cosmics

- Successful operation
- Negligible leak rate
- Wrong gas ($ArCO_2$ for safety)

This one will NOT stop the show

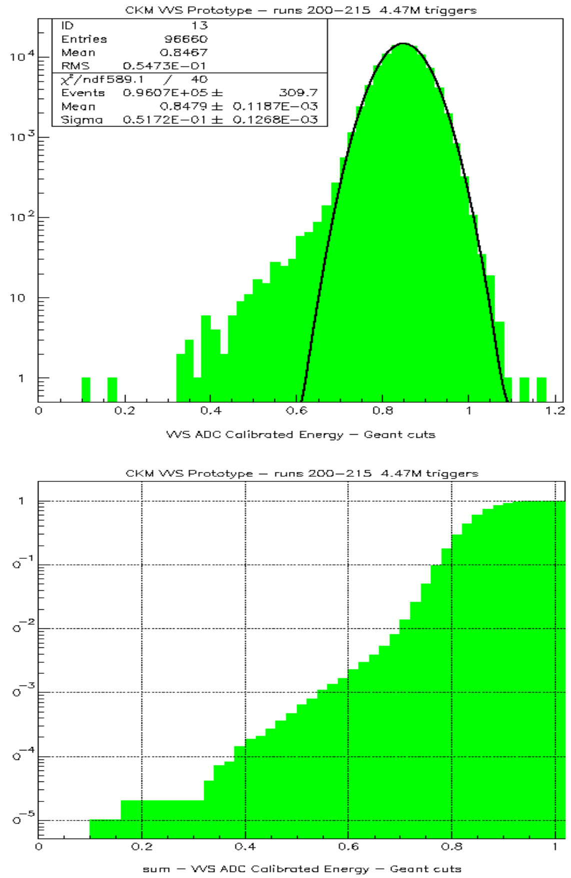


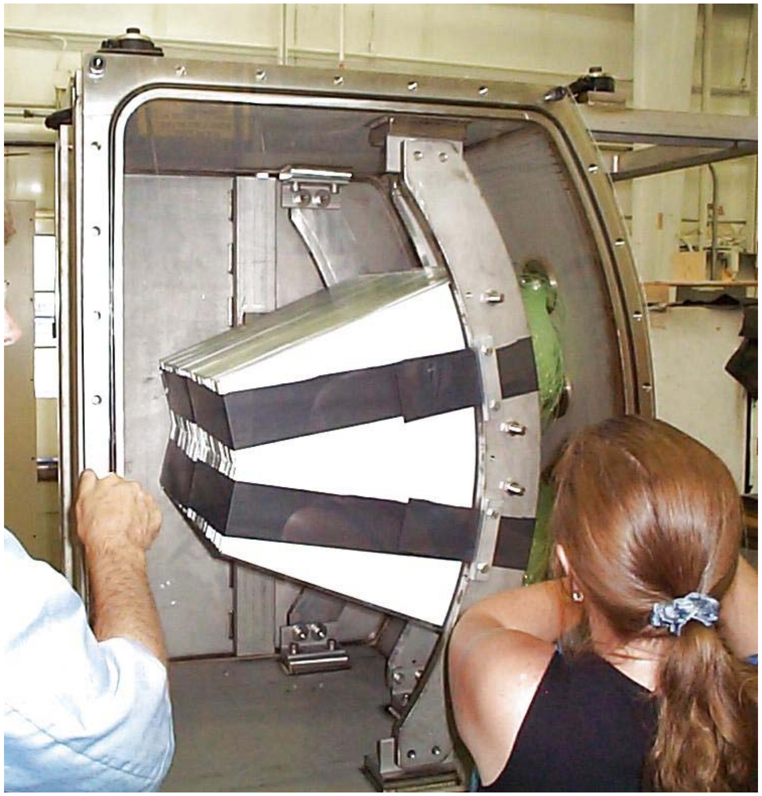
C3 Technical Concern from Approval review: 3×10^{-5} photon veto inefficiency at 1 GeV

0.3% VVS Prototype built

Tested at JLAB in an e^- beam

Achieved $<1 \times 10^{-5}$ veto inefficiency at 1 GeV





Q3 What is the timeline/schedule?

- CKM LOI in 1996
  1st proposal 1998 (unconsidered)
  2nd proposal considered and approved 2001
  Prototypes and testbeam work completed in FY03
  SCRF production prototype in FY04

- Scope of project is very similar to KTeV

- We require a 3 year funding profile to built the beam and detector
- 1 year of commissioning – some overlap with construction is possible
- 2 years of data taking

- When might we start?